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Wetland Shoreline Protection and Erosion Control: Design Considerations

PURPOSE: This technical note summarizes information and documented experience concerning wetland protection and erosion control along channels and shorelines. The causes and mechanisms of erosion are described, and general design requirements that should be considered when planning an erosion control project are outlined.

BACKGROUND: Shorelines and structures associated with created and restored wetlands are exposed to the erosive forces of nature. Wetlands invite the use of more natural vegetative solutions for erosion control and a greater emphasis on project aesthetics than in other types of erosion control projects. Sometimes, vegetative techniques alone cannot provide adequate protection of wetlands, and they must be combined with other alternatives. A design goal for a wetland protection project should be to use the minimum amount of structural protection necessary. Innovation is often the key to an appealing and successful project.

DEVELOPING A WETLAND EROSION PROTECTION PROJECT: The process of developing an erosion protection project can be described in several steps (Figure 1). It should be noted that, in many cases, there is significant overlap and iteration between steps. Other important checklists are also included in Figure 1.

DETERMINING THE CAUSES AND MECHANISMS OF EROSION: The causes of wetland erosion, which are discussed below, play an important role in determining the protection alternative that is selected for design and implementation.

- *Wind and boat waves* are often the dominant cause of local instability in tidal wetlands and along fringe wetlands in lakes. Waves erode the bank near the waterline, and can undercut banks, leading to mass failure. The failed material piled at the toe of the bank is washed away by subsequent waves, and the undercutting cycle continues. Boat waves differ from wind waves in their size, frequency, and duration but, otherwise, have similar erosion mechanisms.

- *Boat-induced currents* can cause instability in wetlands, especially where large vessels travel in narrow, confined waterways or where large, commercial vessels travel near bank lines in larger waterways. Boat-induced currents are caused by the propeller jet and by vessel displacement effects. The erosion zones may be on the bottom and sides of the waterway.

- *Channel meander* is caused by current-induced forces. Erosion occurs on the downstream part of bendways and is most severe at intermediate to high stages. As material is removed from the toe of the bank, the bank is undermined and fails. The failed material is removed by the flow, and erosion continues.

- *Channel braiding* occurs on streams with an overload of sediment and/or steep bed slopes where bars and islands can form, producing a wide, shallow channel. The bars and islands may become wetlands. Erosion of banks, islands, and bars in braided channels occurs as a result of flow being diverted against the bank by the bars and islands. Erosion is variable and can occur at any position along the length of the channel.

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Steps in developing an erosion protection project:

1. Understand the system and determine the mechanisms and causes of erosion.
2. Consider general design requirements.
3. Develop a list of alternatives to protect against the cause of the erosion problem.
4. Design the protection.
5. Estimate the costs of the project.
6. Construct, inspect, and maintain the project.

Causes of local bank and shoreline instabilities in tidal and riverine environments:

1. Wind and boat waves.
2. Boat-induced currents.
3. Channel meander.
4. Channel braiding.
5. Ice and debris.
6. Water-level fluctuation.
7. Flow constrictions.
8. Other (rainsplash, freeze-thaw, overbank drainage).

Important factors in designing erosion control projects:

1. Geomorphology.
2. Ecological and physical barriers.
3. Aesthetics.
4. Habitat diversity.
5. Hydraulic setting (design event, water-level fluctuations,
   wind waves, currents, etc.)
6. Top elevation of protection.
7. Toe and flank protection.
8. Geotechnical setting.
9. Surface drainage.
10. Filter layers and fabrics.
11. Safety factor.
12. Locally available materials.
13. Vandalism.
14. Public education.
15. Fate of materials.
16. Effect of alternative on local waves and currents.
17. Access.
18. Animal activity.
19. Water chemistry.
20. Construction and ease of repair.
21. Navigation hazard.

Figure 1. Checklists for planning wetland shoreline protection and erosion control

- *Ice and debris* can reduce flow area and concentrate or deflect flow against otherwise stable bank lines, causing erosion. Ice and debris can gouge bank lines, damage vegetation, and damage improperly designed protective measures.

- *Water-level fluctuation* is a cause of instability in riverine, depressional (reservoirs), and tidal wetlands. Water-level fluctuations allow waves and currents to erode a bank at ever-changing elevations. Causes of water-level fluctuations include naturally varying and controlled stream discharges and lake levels, astronomical tides, seiches, wave setup, climatological effects, and navigation.

  A rapid drop in water level leaves saturated banks in an unstable condition. On steep banks, mass failure may occur. On banks containing layers of different materials, a rapid drop in water level causes saturated banks to drain through the more porous layers. Flow through these porous layers may remove material, leading to bank collapse. This process is called piping or sapping and is also found in environments not having rapid drawdown but having saturated overbanks from ponds or poor drainage.

- *Flow constrictions* at bridge crossings, training structures, and floodplain encroachments can increase flow velocities that may erode otherwise stable banks.

- *Other causes* are rainsplash, freeze-thaw, and overbank drainage. Overbank drainage and rainsplash tend to produce small, local instabilities; nevertheless, these processes should be considered in designing protection methods. Freeze-thaw decreases bank soil strength, which increases the potential for the removal of bank material.

GENERAL DESIGN REQUIREMENTS: To ensure effective erosion protection, a number of design factors should be considered. These factors, listed in Figure 1, are discussed below.

- Geomorphology. Geomorphic evaluations involve determining the beginning point, ending point, and alignment of the protection. The protection may only need to extend along a limited reach of the threatened wetland. In other cases, the protection may have to be extended beyond the limits of the threatened wetland to ensure adequate protection over the design life of the project. For habitat and aesthetic reasons, less emphasis is given to a straight or smooth alignment for wetland protection. However, wetland boundaries may be aligned for reasons of project function and economy. For example, a proposed island wetland restoration design in the Chesapeake Bay had a circular planform that minimized the length of exterior erosion while maximizing the interior wetland area.

- Ecological and physical barriers. Animals should be able to move in and out of the wetland. Steep banks with crevasses (for example, in riprap) may trap small crustaceans and young animals. The protection should not adversely limit the amount of water that flows through the wetland. Improper flows may alter the hydrologic characteristics, water temperatures, dissolved oxygen, and other chemical constituents within the wetlands. If the export of nutrients from the wetland is important, sufficient flows must be achieved to accomplish it.

- Aesthetics. In a wetland environment, preservation of a natural appearance is important from both human and wildlife perspectives. The impact of protection methods on aesthetics depends on the degree to which the protection measures are visually compatible with their surroundings (Henderson 1986).

- Habitat diversity. Development and preservation of habitat and habitat diversity should be high priorities. Diversity of aquatic habitat is the result of diverse depths and velocities. Bank protection methods, such as the indirect methods of dikes and groins, promote diversity of aquatic habitat whereas relatively smooth revetments tend to reduce diversity. Rock structures and other bank protection methods provide stable substrate for macroinvertebrates.

- Hydraulic setting. Quantifying the hydraulic setting is required to determine the causes and mechanisms of bank erosion. Depending on the setting, the effects of hydraulic levels, wind waves, boat waves, currents, and vessels may have varying levels of importance. Guidance for estimating wind waves at a project can be found in the Corps of Engineers' Shore Protection Manual (U.S. Army Corps of Engineers (USACE) 1984). Important variables are the wind speed, wind direction, fetch geometry, and water depth. To determine currents, the channel cross section, inflow rates, and water levels are needed. Flow routing models, such as HEC-2 (U.S. Army Hydrologic Engineering Center 1990), are available to help compute riverine currents.

  Vessel effects are primarily a function of vessel speed, vessel shape and displacement, distance from vessel, and water depth. With regard to vessel shape and displacement, two broad categories are recognized: commercial and recreational vessels. Commercial vessels are relatively slow but have large displacement; recreational vessels are relatively fast but have small displacements. Commercial vessels rarely move fast enough to produce significant waves, but they produce substantial, rapid drawdown when operating in confined channels. Methods for predicting drawdown magnitude and other navigation effects are presented in PIANC (1987). Methods for predicting waves from recreational vessels, which decay with distance from the vessel, are given in Bhowmik and others (1992).

- Top elevation of protection. Wetlands, particularly in a tidal environment, have relatively low top bank elevation, and protection extends over the elevation of the wetland. In the riverine environment, many successful projects have been built with the top elevation of the structural protection well below the top-of-bank or design water surface. Vegetative techniques are often used to protect the upper bank. Factors affecting the required top of structural protection in the riverine environment are stage duration, erodibility of upper bank soil and vegetation, variation of hydraulic forces on the upper bank, bank slope, method of protection, and consequence of failure. Engineer Manual 1110-2-1601 (USACE 1994) presents a method for estimating the variation of hydraulic forces on the bank in the riverine environment.

- Toe and flank protection. One of the most overlooked but critical aspects of bank protection projects is consideration of the toe and ends of the design. In the river, toe scour and the fact that many species of vegetation cannot withstand long-term inundation are the primary reasons that vegetative techniques alone will not provide stable bank protection. Some form of structural protection, often required at the toe of the riverbank, must be able to withstand the changing bed elevation found in alluvial channels. Procedures for estimating toe scour in the riverine environment are given in USACE (1994) and, for the wave environment, in the Shore Protection Manual (USACE 1984).

  Two methods are used to provide scour protection. One is to extend the protection down to the maximum estimated scour depth. This is often the preferred method in dry construction, although it becomes difficult and expensive when excavation is done underwater. Another approach is to place a flexible material that will adjust to the channel scour. This approach lets the stream do the excavation. Riprap is the most common material to use in flexible or “self-launching” aprons. Gabions and cabled concrete block mattresses can also be used to provide a flexible toe structure. Guidance for self-launching riprap and scour depth estimation in the riverine environment is given in

USACE (1994). The Shore Protection Manual (USACE 1984) provides guidance for self-launching riprap in the wave environment.

When considering the ends of the protection, it is desirable to terminate the protection in areas where the erosion forces are reduced. Unfortunately, this is frequently not possible, and the ends of the protection must be designed to not fail when the adjacent unprotected areas experience erosion. When using armor protection such as riprap, increased layer thickness at the ends will allow the protection to adjust to minor adjacent erosion.

- Geotechnical setting. Geotechnical design considerations include slope stability, filters, and subsurface drainage. Slope stability deals primarily with the stable bank angle, which is a function of height, bank material, stratigraphy, stage fluctuation, groundwater conditions, and overbank loading. The purpose of filters and subsurface drainage is to control the movement of water and bank material beneath and through the protection.

- Surface drainage. Surface drainage rarely causes failure of a protection alternative, but may cause maintenance problems, destroy vegetation, and damage the aesthetics of a site. The basic steps in preventing erosion from surface drainage are to protect all bare ground (unless slopes are flat, and wavewash and runoff are moderate), collect overland flow and wavewash in channels, and provide return-flow outlets.

- Filter layers and fabrics. Many protection alternatives require a filter layer at the interface of the protection material and the sediment. The filter layer, which consists of well-graded gravel and stone, prevents sediments from filtering through the protection, which would ultimately undermine or destabilize the protection. The filter layer can also distribute the weight of protection more evenly over the substrate. In many instances, a filter layer may be replaced by an acceptable filter fabric, the pores of which are specified based on the characteristics of the sediments.

- Safety factor. The consequences of failure of the protection project must also be considered. Only limited design information is available for many of the bank protection alternatives that might be used in a wetland. Without well-founded design information, determining a factor of safety is difficult. Usually, a conservative design is selected to compensate for uncertainties, or the design is based on the convenience of construction, materials, or some other feature. If the construction environment is difficult or materials lack quality then, as a factor of safety, the design should account for the prospect of sections of below-average construction or low-quality materials. Safety factors can be reduced if inspection and maintenance are scheduled up front. That is, if the project shows signs of failure after a certain operating time, remedial action could be taken to correct the problem.

  An additional consideration is that, for some projects, even though damage or losses would be acceptable to an agency from a financial standpoint, the appearance of failure in the eyes of other agencies is less acceptable. Often, the agency wants the protection to work without failure so that it will be easier to gain approval for additional projects in the future.

- Locally available materials. The cost of any project can be reduced if inexpensive locally available materials are used. A project design should always consider the advantages of using local materials in some element of the design.

- Vandalism. The effects of vandalism must be anticipated, especially in areas where the public has access. To minimize these impacts, hard-to-damage materials and designs can be used, or periodic maintenance can be planned. Consideration should be given to using a protection scheme that will work in spite of damage to some portions of the project.

- Educating the public. Educating the public to the purpose of the project and making them feel a part of the project may help reduce the frequency of vandalism or inadvertent damage caused by people working or recreating in the area. This can be accomplished through nonconfrontational signs and seminars and by enlisting their help in the construction and planning of the project.

- Fate of materials. Project designers must consider the possible fate of materials used in the bank protection design in the event the project fails or exceeds its design life. Many geotextiles, tires, synthetic materials, metals, and treated woods do not degrade rapidly and may remain as an unappealing result of the project or pose a danger to humans and the environment.

- Effect of alternative on local waves and currents. The impact of bank stabilization on areas adjacent to the protection must be considered in the design. In a naturally eroding stream system, bends migrate downvalley. By stabilizing one portion of this system, the natural downvalley movement is interrupted. The stabilized section causes the point of attack in the next downstream section to be fixed rather than transient. Depending on bank erodibility and other factors, this constant point of attack can alter downstream erosion patterns and rates. Bank protection that significantly reduces channel area or deflects currents can increase downstream or opposite bank erosion.

  Bank protection alternatives may influence the wave field near the protection. Waves refract and diffract near bathymetric variations and structures. For example, refraction will cause wave crests to bend around a mound of material on the bottom. The wave crest may bend so much that it collides with itself on the backside of the mound. The colliding wave crests can damage shorelines or protection works where otherwise the wave may have had little effect. Waves that pass by the end of a structure, such as a breakwater, will diffract into the region behind the breakwater and may cause unexpected damage.

- Access. If the public has access to the site, the protection project must not present a danger to them or their property. Access also affects the selection of the protection method. In some projects, land access for construction may not be feasible. In many of these same projects, water access by large construction equipment is limited by shallow depths. Where larger construction equipment does not have access to the site, more labor-intensive alternatives may be required.

- Animal activity. Animal activity in and adjacent to protection methods can undo otherwise stable systems. Certain coastal crab species burrow passageways into exposed banks. These passageways, especially in conjunction with rapid drawdown from tows in confined waterways, can lead to a piping-type failure of the bank. Conversely, certain types of bank protection structures may create an ecological problem by preventing the use of the bank by such burrowing animals. Another type of animal activity that has repeatedly caused problems is the consumption and destruction of vegetation protection systems by various animal species. Whenever vegetation is used in a project, damage to the plants by animals and techniques to prevent such damage should be anticipated.

- Water chemistry. In tidal wetland environments, the tolerance of protection materials to seawater must be considered. Metals will corrode, and timber will rot. Also, certain species of vegetation are intolerant of high or low levels of salinity.

- Construction and ease of repair. Conditions at the project site (dry, soggy, or submerged) can dictate the type of alternative selected because of the limitations on equipment types that can be used. Costs must be increased to overcome poor construction conditions. Likewise, repairs or modifications will probably be costly as well. Thus, the ease of repair should be considered when designing the project and predicting future maintenance costs.

- Navigation hazard. If the public has access to the site by water, possible hazards to navigation need to be considered. This can be a problem if part of the protection includes partially or fully submerged structures both offshore and on the bank.

SUMMARY: The information presented in this technical note is intended to be used as a checklist of important design considerations. It is highly recommended that project designers refer to the resource documents cited herein and consult with experienced engineers or scientists knowledgeable of wetland erosion protection.

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